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Design and Development of a Portable Hybrid Power Generation System for Rural and Urban Areas Applications

Antonio-Abdu Sami M. Magomnang* and Aimee D. Cadungog

Department of Mechanical Engineering, University of Science and Technology of Southern Philippines – CDO Campus, Lapasan, Cagayan de Oro City, Cagayan de Oro, 9000 Misamis Oriental, Philippines; a_magomnang@yahoo.com, cadungog97@gmail.com

Abstract

In far-flung rural and urban areas, one of the major problems typically encountered is the shortage or non-availability of electricity. Installation of electrical lines becomes expensive due to the far distance from the nearby electricity facility. This leads to the utilization of renewable energy such as biogas have been considered as an alternative source. Biogas produced naturally when an organic material such as animal manure, agricultural waste decomposes under anaerobic conditions. **Objectives:** As a solution, this study aims to develop hybrid power generating systems as a source of electricity from biogas, thermoelectric module and solar panel to supply the needs of the community through renewable energy. **Methods:** It uses digester, water jar for CO_2 removal, PVC pipe used for manure inlet and H_2S removal with ten (10) iron sponges to produce high methane content biogas in order to sustain the co-generation of energy from the thermoelectric module and solar panel. **Findings:** The data generated in the developed portable hybrid generation system shows that a mixture of pig and cow manure with a mixture ratio of 1:3 is capable in the production of methane content higher than 50% and this was tested by cooking at various conditions. Further, co-generation of electricity using the solar panel and the thermoelectric generator produces a combined electrical power of 5 watt-hours in just 30 minutes, which is capable to charge digital devices and supply a 30 watts light bulb for 2 hrs. **Application:** This study suggests that energy from biogas can be utilized for cooking and as a source of electricity using the co-generation of energy from the thermoelectric generator and solar panels.

Keywords: Biogas, Cogeneration, Power Generation, Solar Energy, Thermoelectric Technology

1. Introduction

Renewable energy is very essential nowadays. However, there is still a need to optimize and further develop these technologies for sustainability depending on the area, availability, and the community needs. The increasing number of swine farms, poultries in the Philippines creates problems on waste disposal affecting human health and the environment. In this case, the design of digesters helps to lessen these problems, but technical constraints and the high cost of investment prevent the use of biogas digesters in rural areas. There are researches from the Department of Agriculture-Western Mindanao Integrated Agricultural Research Centre led by[1] evaluated three types of biogas digesters to determine the design suited to the villages. Based on his experiments, it has been observed that the highest production of gas was made by the commercial type digester.

Findings show that bio gasification or the microbial conversion of organic matter in anaerobic conditions offers a systematic approach to manure treatment that does not only stabilize the waste but also produces a significant amount of energy in the form of biogas. This comes up in an idea of gaseous fuel that could replace traditional wood-based cooking and generate electricity through thermoelectric generator for electricity generation. The biogas

**Author for correspondence*

system is a connection of an anaerobic digester. The anaerobic digester servers produce biogas for cooking purposes. It is important to remove the impurities for health safety.

For electricity generation system, it has the Thermo-Electric Module (TEM) which converts the thermal energy into electrical energy. An add-on solar panel will generate electricity from the sun substitute to when there is thermal energy generated by the TEM. The Solar and TEM is connected to a charge controller to the battery for electricity source. In addition, mobilized set up is designed to make it easy to transport in case of any variation of weather conditions.

This study aims to develop hybrid power generating systems as a source of electricity from biogas, thermo-electric module and solar panel to supply the needs of the community through renewable energy for rural and urban areas deployment.

2. Methodology

2.1 Design of Hybrid Power Generation System

The conventional biogas system is put in a certain area that enough to produce biogas. In this study as shown in Figure 1-3, the use of the wheel and a carrier is essential enough to be the biogas system transferable. The experimental methods are to get the electric generation of the biogas. A TEM and a Solar Panel are the most indispensable of producing electrical energy which then stores in the battery. The stored energy then uses in charging devices like cell phones and other devices that is chargeable. The fabrication of the system is fabricated enough to withstand the weight of the manure and other materials that it carries.

2.1.1 Design Requirements

The amount of manure that is put in the digester is by a batch process. A 7.5 kg of pig manure plus 22.5 kg of cow manure a total of 30 kg is mixed with 30 kg of water a total of 60 kg substrate. A capacity of 100 liters plastic is design in which almost ¾ of the volume is occupied by the substrate.

The design of the digester tank (Figure 3) is intended for mono and co-anaerobic digestion for biogas production and removal of impurities. Base on the digester tank that we used, we only choose the manure for our final set-up base on the highest value of methane and heating value produced.

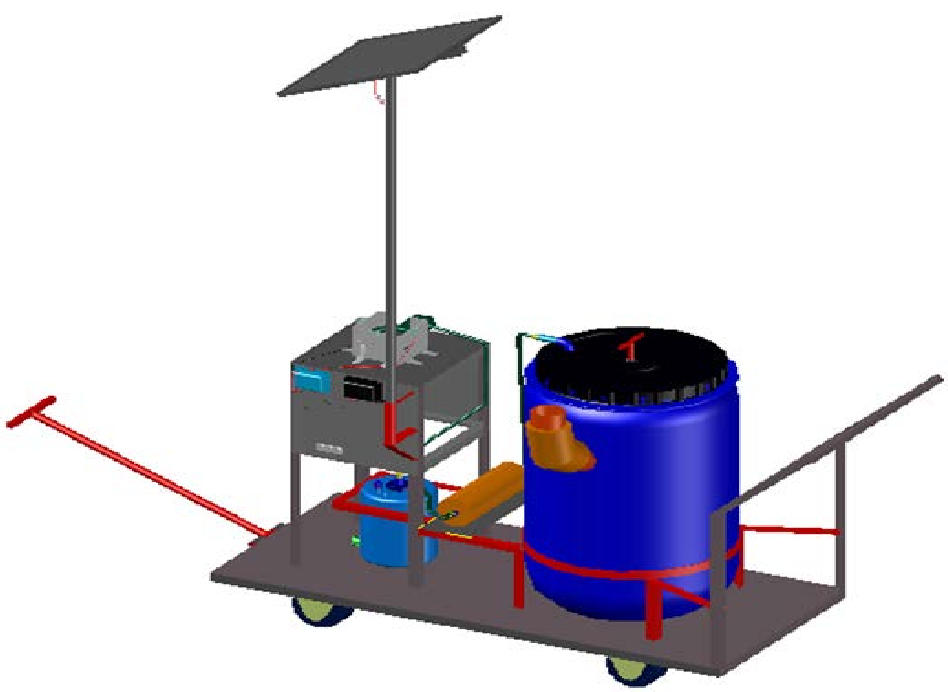


Figure 1. Orthographic sketch of the set-up.

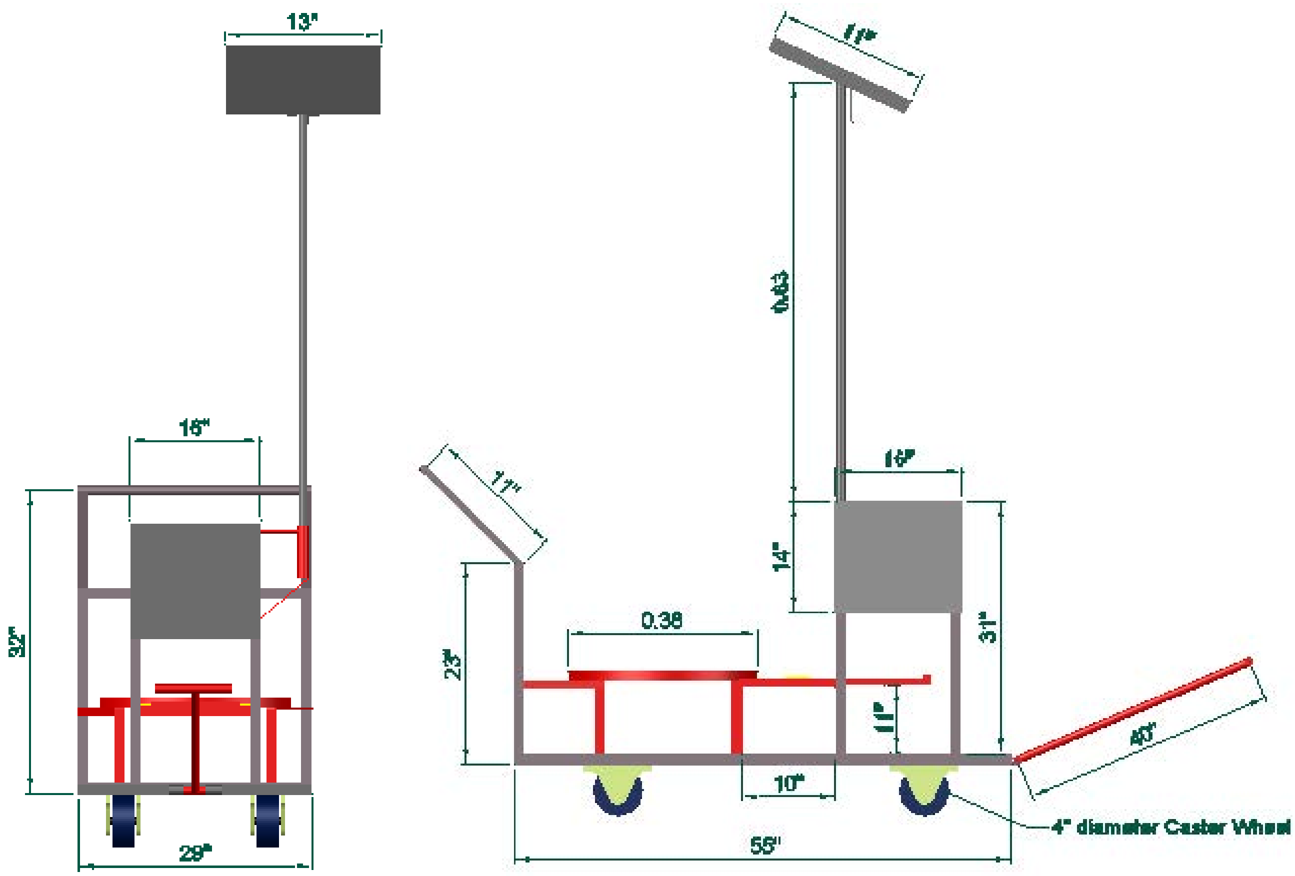


Figure 2. Right and front view of the digester.

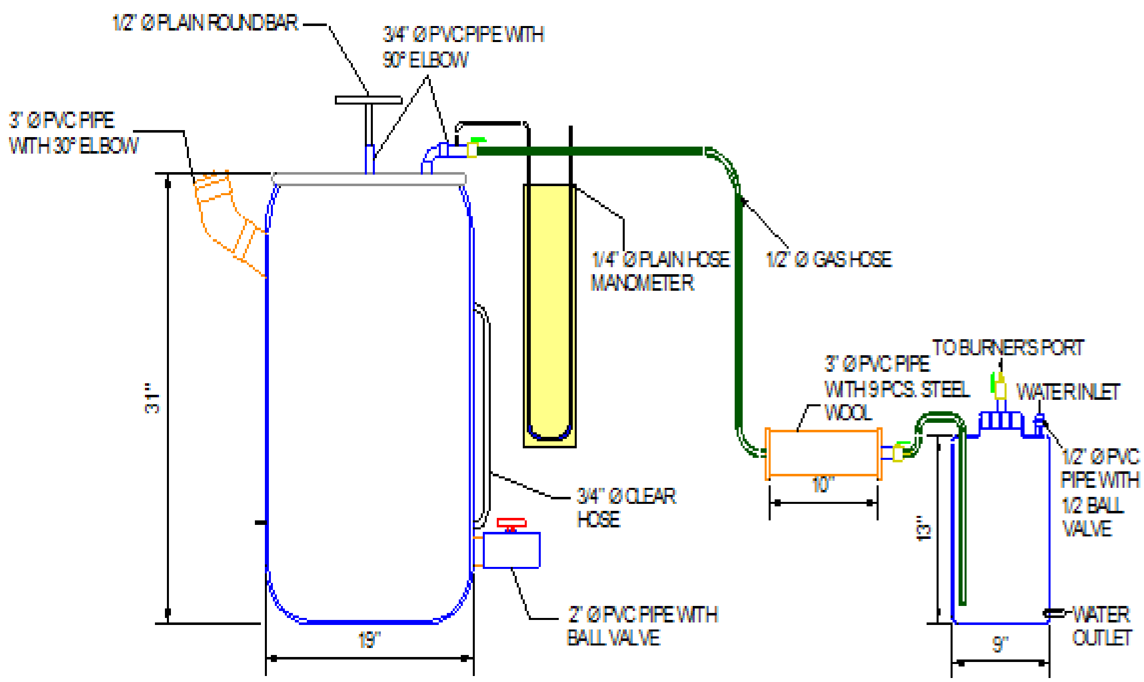


Figure 3. biogas system schematic flow.

Based on the digester tank that we used which is 100 liters capacity, biogas must be extracted on the final manure to be used. The design is intended to surpass the internal pressure in the digester, enough to avoid an explosion. The carriage design is intended for making the removal of impurities, digester, the location of the battery, charge controller positioning and solar panel are stable when it moves to another place. Also, the design of the biogas system is designed to carry the overall weight that is put on it.

Figure 4. Burner used as a component in the hybrid power generation system.

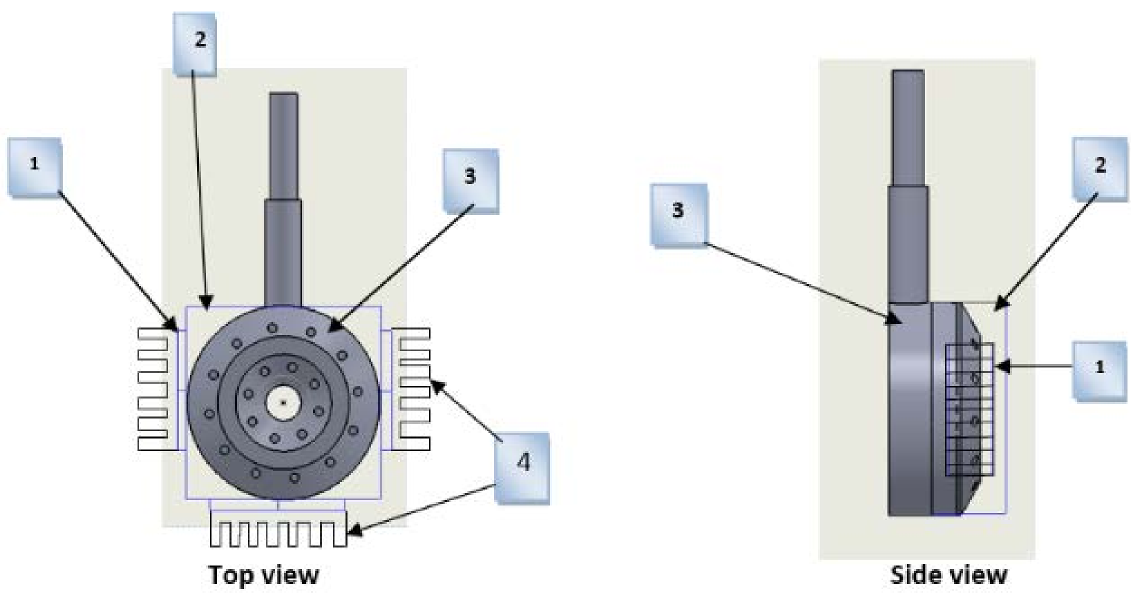


Figure 5. Burner design for the installation of thermoelectric module.

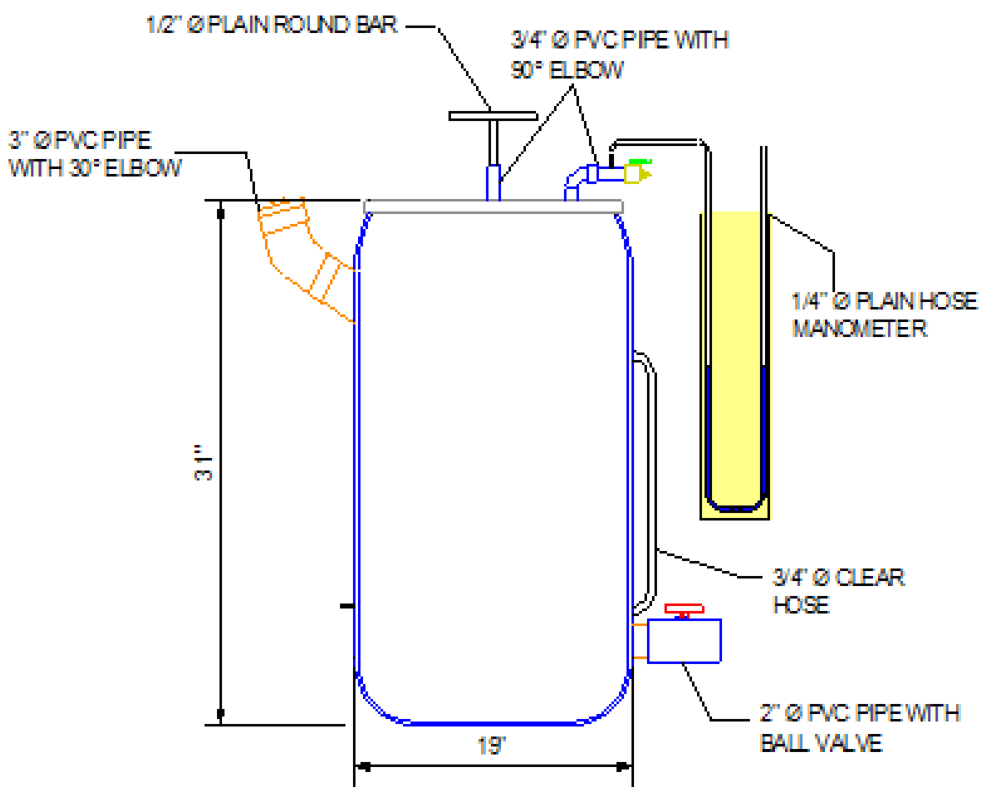


Figure 6. Designed biogas digester.

2.1.2 Installation and Detailed Outline of Materials

Figure 4-7, state the actual design, labeled and sizes of the materials used in installation and fabrication of the hybrid biogas system. In which, the researchers use a material that preferably available in the market, not only the cost is low also it is durable and rigid enough to sustain the need of the system. The researchers use a thermoelectric module in which the specs are listed below. A 0.5-in diameter port burner are market base standard. A volume of Model: TEC1-12706; Size: 40mm x 40mm x 3.9mm; Voltage and Current: (Vmax: 15 V, current 5.8A); Solder Construction: 138.

A three-length of angle bars for the carriage fabrication. Digester drum of 8789.39 in^2 of volume, in which the components that are shown in the picture 7 functions as the inlet and outlet of manure and biogas. An 827 cubic inch volume of CO_2 removal container with two 0.5 inner diameter ball valve. All stated materials that are mention above have the big rule to make the system functional.

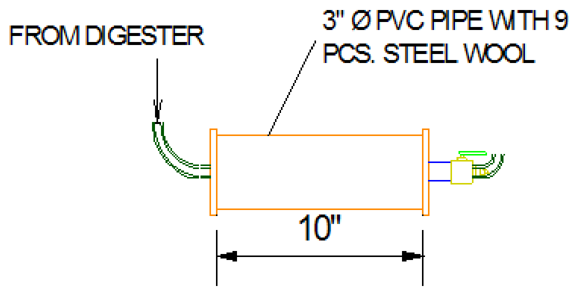
3. Results and Discussions

3.1 Designed Hybrid Power Generation System

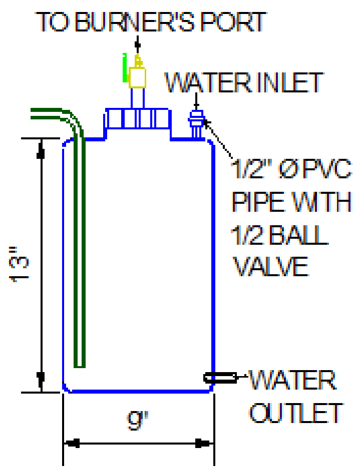
Choosing appropriate materials is very important in the proposed hybrid power generation system design, especially in the digester because it is the one who holds the internal pressure. By selecting the materials, we just not know its properties, but also connected to other materials and component used in the system.

In order to know its properties and advantages towards to others, the researchers used Ultra High Molecular Weight Polyethylene (UHMWPE) plastic for digester and gas holder against fabricated steel containers. Besides its low-cost, we can assure that it is free from corrosion and also it is rigid, durable and lightweight.

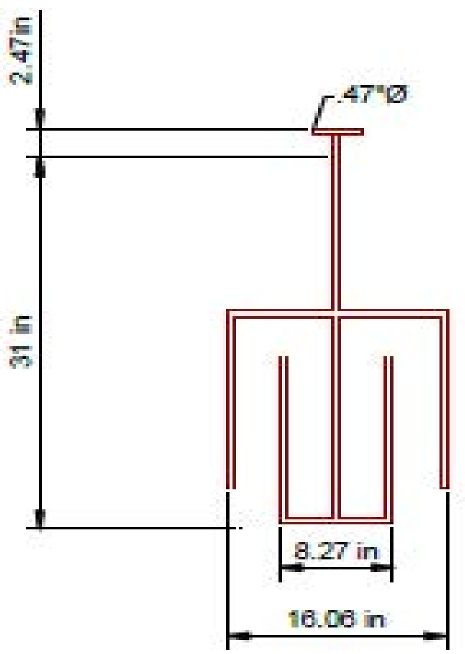
The hose that connects the digester to the gas holder and to the other impurities removal was a pneumatic hose since it is used in hydraulic application it ensures durability and safety, the most important is that it can withstand pressure inside the digester as shown in Figure 8.



(a) H_2S Removal

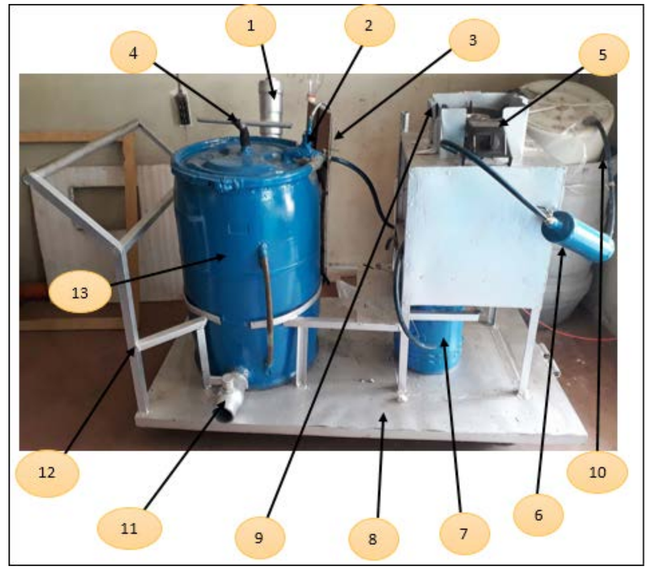


(b) CO_2 removal



(c) Stirrer design

Figure 7. Other Components of the portable power generation system.



Legend:

(1) Manure Inlet;	(2) Gas Outlet;
(3) Manometer;	(4) Agitator/Stirrer;
(5) Burner;	(6) H_2S Removal;
(7) CO_2 Removal;	(8) Carriage base;
(9) Thermoelectric Module;	(10) Gas Holder;
(11) Slurry Outlet;	(12) Carriage Handle (Push);
(13) Digester.	

Figure 8. Developed biogas system.

3.2 Evaluation of the Developed Portable Hybrid Power Generation Systems

3.2.1 Evaluating the Biogas System Production Parameters

Based on the cow and pig digestion, the slurry and ambient temperature are both measured as shown in Figure 9. It was observed that the temperature throughout the hydraulic retention time was in the mesophilic temperature range which is around 20°C – 40 °C[3]. Having the maximum slurry temperature ranges from 30°C – 33°C. The graph in Figure 10 shows a consistent pressure of approximately the same as the atmospheric pressure of 14.7 psi. It was almost the same for the entire experiment since the water inside the manometer has a minimal rise in height. Since the pressure inside is not accumulated because of every other day testing of the gas port which lead to the release of pressure inside the digester. Throughout the anaerobic digestion process as shown in Figure 11 observed that the pH value ranges from 6.4 to

6.9 which are due to the processed caused by the methanogenic bacteria. In order to obtain the best-optimized condition for biogas production, where the methane-producing bacteria exist, the pH value of the input mixture in the digester must be maintained between 6 and 7[2].

The pig and cow manure hydraulic retention time under mesophilic temperature range is 15-30 days[4]. Further, the substrate mixtures start producing gas in the third (3rd) day as shown in Figure 12. During the experiments, the cow manure to water ratio of 1:1 has the highest methane content among other ratios presented. It also implied that cow manure has a good gas performance in cooking. Further, in terms of 1 kg of cow manure and 1 litter water ratio generates the highest reading result hav-

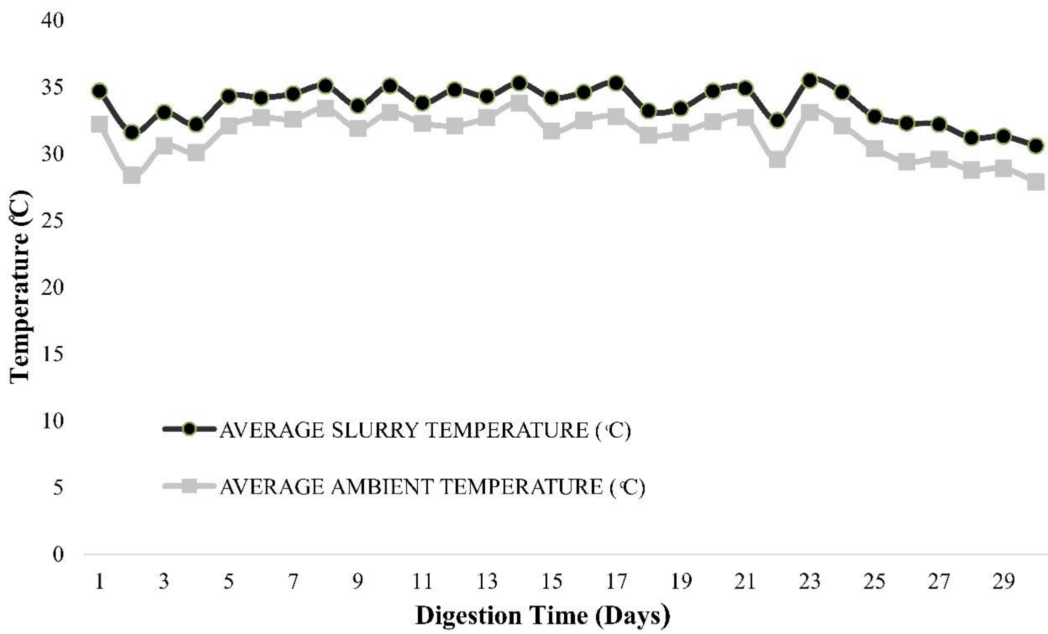


Figure 9. Digester temperature.

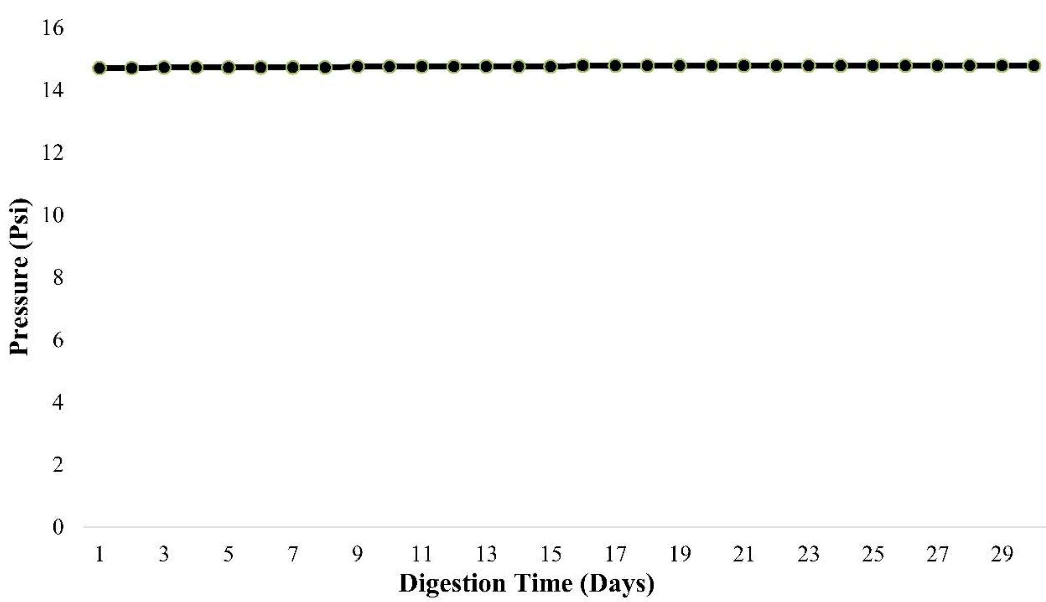


Figure 10. Digester pressure.

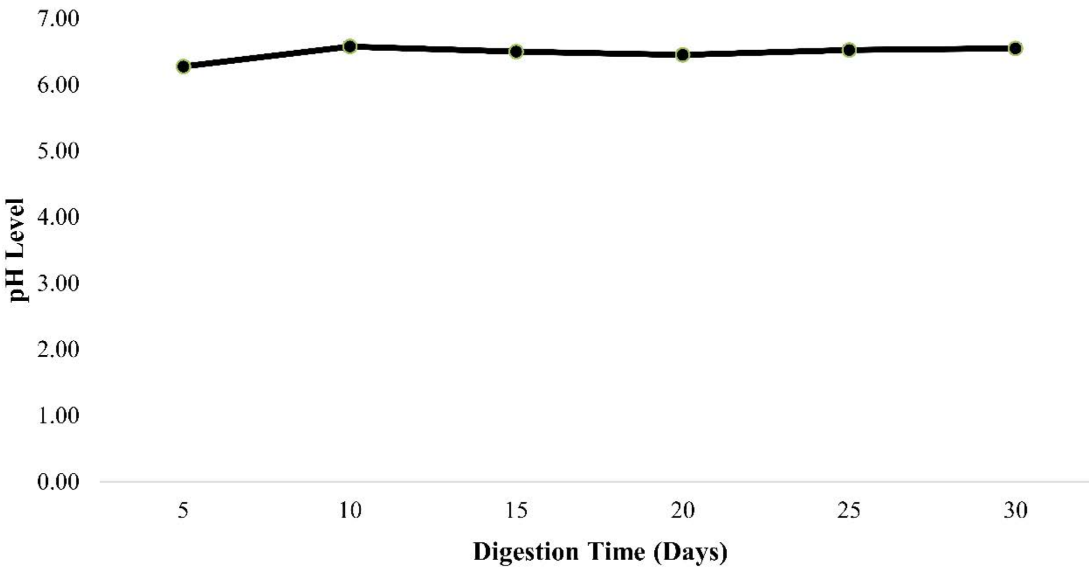


Figure 11. Digester pH content.

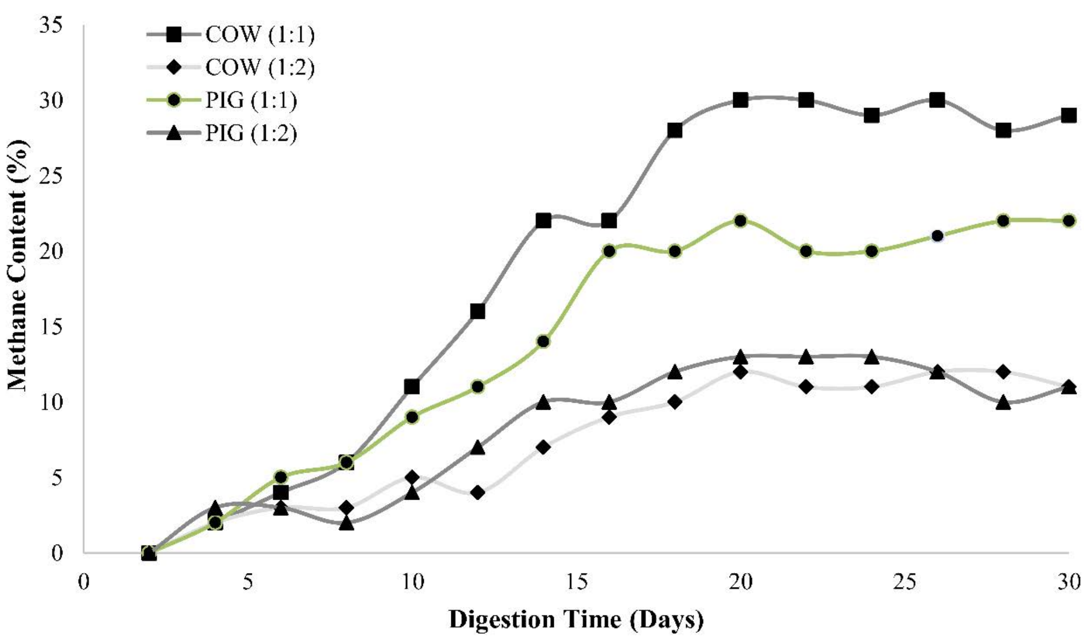


Figure 12. Methane production for 30 days digestion time.

ing 30% methane concentration with an average production of 19.13% by volume. The first 20 days of the entire retention time involves no addition of a floating gas holder since we only fill half of the maximum capacity of the digester. Figure 13 shows how the pressure rises as the day's increases. During the first 5 days, it can be observed that an abrupt and sudden rise in pressure happened. This is due to the increased production of biogas inside the digester. Since the volume of the biogas is proportional to its pressure.

Since the digester cannot contain the biogas production anymore by itself, the design researcher decided to install a floating drum gas holder. Besides, the digester cannot withstand the pressure anymore of the still increasing production of biogas. As the graph shows, the pressure is nearly approximate to the atmospheric pres-

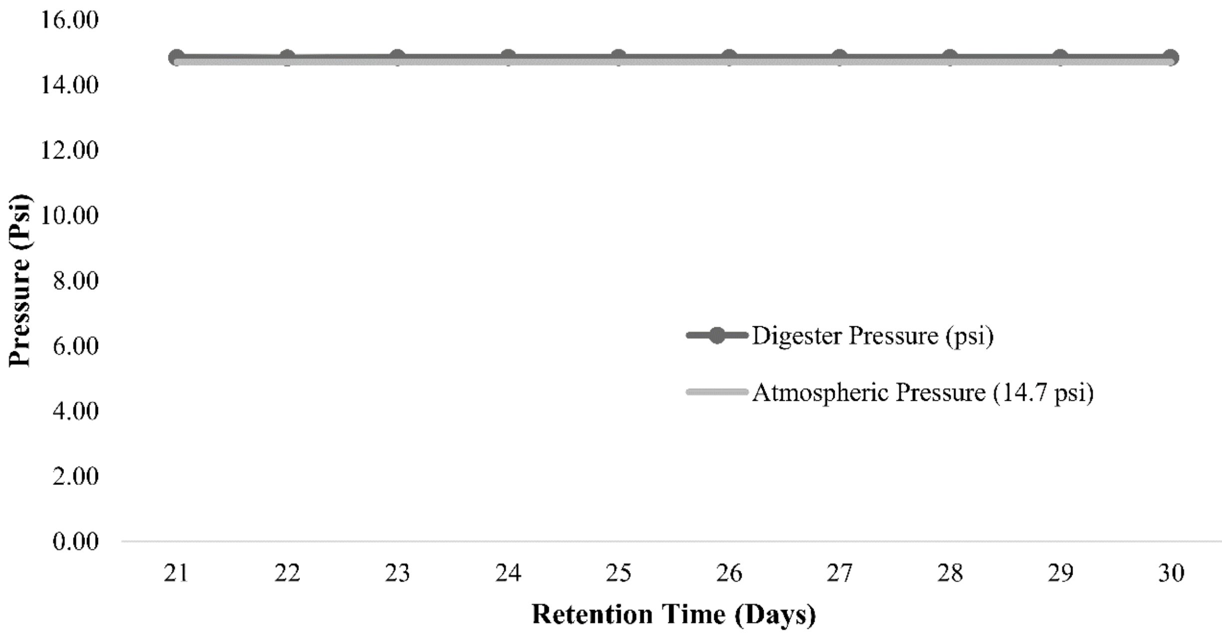


Figure 13. The pressure inside the digester with the installation of floating drum.

sure which is 14.7 psi (Figure 13). This is because the gas holder is expandable and there is a lot of room for the biogas. For a biogas system with floating gas holder as in this experiment, the pressure must be around 14.7 – 14.9 psi[5].

3.2.2 Evaluation of the Installed Solar Panels

Figure 14 shows the conducted experiment starting December 24, 2017, to January 2, 2018. Based on the graph, the energy generated is considerably small for the 10 watts' solar panel with dismal result due to rainy weather conditions.

On day 4 (December 27, 2017) and day 9 (January 1, 2018) shows the lowest generated energy (6.50 watt-hour in 11 hours per day) as these were rainy days. Day 5 shows the highest generated energy (47.89watthour in 11 hours per day) as it was sunny day with clear sky. For the highest generated energy, it took 14 hours to make the 60-watt-hour battery fully-charged while for the lowest generated energy, it took 103 hours to make the 60-watt-hourbattery fully-charged. For the 10 watts solar panel and the efficiency is considerably small because of the rainy weather in the month of December. According to[6] the solar panel efficiency is increased when the density of the sunlight increases, it has been observed that the total efficiency of solar modules varies at different temperatures.

3.2.3 Evaluation of the Energy Generated through Burners

The approximate heating value reaches 260 kJ/kg based on 1000 milliliters of water boiled. The boiling of water occurs at the 33min (Figure 15) of the experiment. However, the typical energy content of biogas ranges from 22 to 26 MJ per cubic meter when its methane content is 60% to 70%[1].

4. Conclusion

Biogas production helps the communities in sustaining the needs of energy and the way of living like cooking. With this, the design must be accurate and concrete in order for the system functional. This must be designed in a way that it can be portable, also the whole design can withstand the appropriate pressure and weight required of the system.

The experiment provides how the system works, what is the behavior of the gas content that the biogas produces. The results show the methane content of the system is capable of power generation such as boiling and cooking. The results of test declared indicated the system is functional and it is useful as an alternative renewable fuel for cooking and energy production.

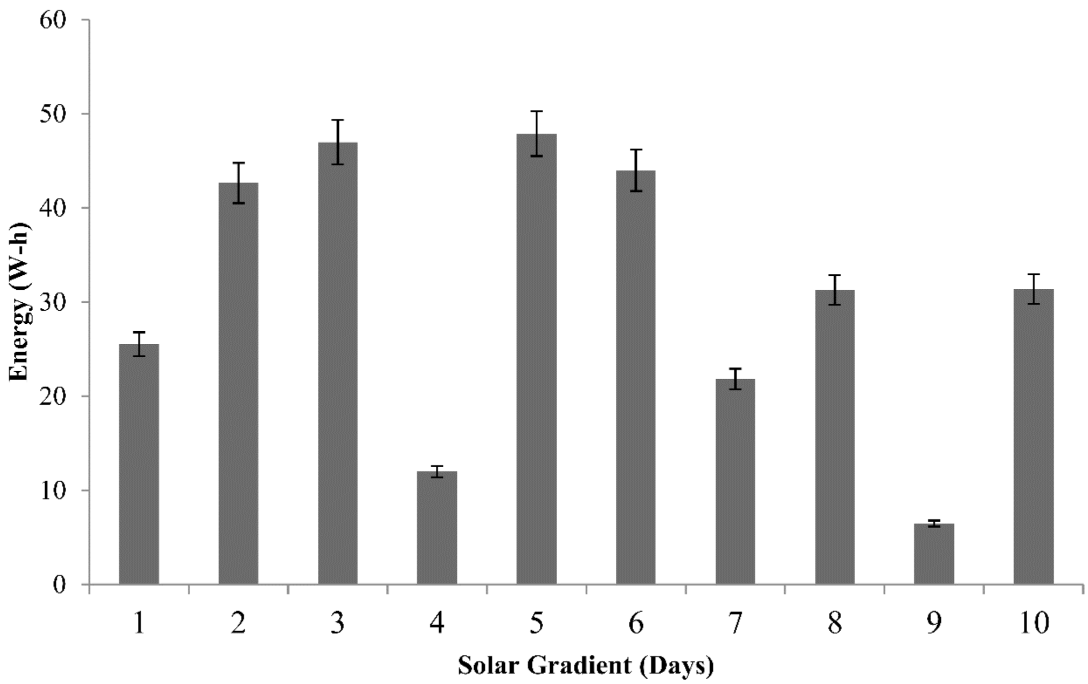


Figure 14. Energy produced in the 10-day solar period by the solar panel.

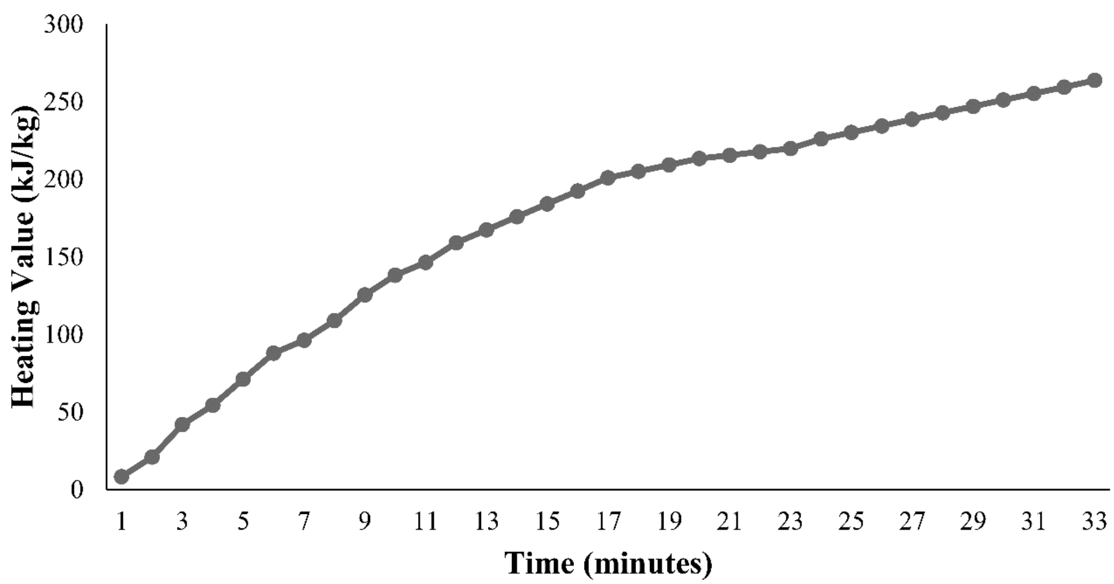


Figure 15. Approximate heating value generated from the produced biogas.

The following steps are recommended for further studies: 1. Well design agitator must be installed in the digester to help faster digestion and appropriate materials in making manometer, 2. A standby gasholder must be installed in the system so that enough gas must be collected and enough for the cooking process, also, proper fabrication and installation of the system carriage to prevent deformation of materials if possible, in the flat areas, and 3. Further testing of the biogas system until it reaches its degradation period.

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